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KS 1855-2 (2008) (English): Thermal solar systems and components — Custom built systems — Part 2: Test methods (Draft Standard)

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KENYA STANDARD

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ICS 27.160; 97.100.99

Thermal solar systems and components — Custom built systems — Part 2: Test methods

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The following organizations were represented on the Technical Committee

Kenital Solar (K) Ltd
ASP Solar (Kenya) Ltd
Sollatek Ltd
Department of Electrical & Electronic Engineering, JKUAT
Renewable Energy Department, Ministry of Energy
Chloride Exide Kenya Limited
Energy Alternatives Africa Ltd
Solarnet
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KS 1855-2:2008
ICS 27.160; 97.100.99

Thermal solar systems and components — Custom built systems — Part 2: Test methods

KENYA BUREAU OF STANDARDS (KEBS)

Head Office: P.O. Box 54974, Nairobi-00200, Tel.: (+254 020) 605490, 602350, Fax: (+254 020) 604031
E-Mail: info@kebs.org, Web:http://www.kebs.org

KEBS Coast Region
P.O. Box 99376, Mombasa 80100
Tel: (+254 041) 229563, 230939/40
Fax: (+254 041) 229448
E-mail: kebs-msa@swiftmombasa.com

KEBS Lake Region
P.O. Box 2949, Kisumu 40100
Tel: (+254 057) 23549,22396
Fax: (+254 057) 21814
E-mail: kebs-ksm@swiftkisumu.com

KEBS North Rift Region
P.O. Box 2138, Nakuru 20100
Tel: (+254 051) 210553, 210555

Foreword

This Kenya standard was developed by the Renewable Energy Resources Technical Committee under the supervision of the Electrical Industry Standards Committee and is in accordance with the procedures of the Bureau.

Quality assurance is of primary importance for large custom built systems. The total investment cost for such systems is higher than for smaller ones, although the specific investment cost (i.e., per m^2 collector area) is lower. The potential of large custom built systems from the point of view of conventional energy savings is much larger than for smaller ones. Moreover, the return-on-investment is in many cases more favorable for large systems than for small ones. Hence, the purchasers of large custom built systems are interested in efficient, reliable and durable systems, the thermal performance of which may be accurately predicted, checked and supervised.

The test methods in this standard provide a means of verifying the compliance of large custom built systems with the requirements in KS 1855-1.

As large custom built systems are by definition unique systems, only general procedures on how to check and supervise them may be given. An additional difficulty in the formulation of procedures is the fact that they have to be adapted to the dimension of the large custom built system considered, which may vary from typically 30 to 30000 m^2 of collector area. Therefore, several possible levels of analysis are included (annexes C and D).

The objective of the two short-term system tests presented in Annex C is the characterization of system performance and/or the estimation of the ability of the system to deliver the energy claimed by the designer. In principle, two approaches for short-term system testing are referred to in this standard:

a) A simplified check of short-term system performance, carried out by intercomparison of the measured solar system heat gain with the one predicted by simulation, using the actual weather and operating conditions as measured during the short-term test.

b) A short-term test for long-term system performance prediction. The performance of the most relevant components of the solar heating system is measured for a certain time period while the system is in normal operation. More detailed measurements encompass a) energy gain of collector array(s) and b) energy balance over storage vessel(s). Intercomparison of the observed and simulated energy quantities provides the indirect validation of collector and storage design parameters. The measured data within the collector array are also used for direct identification of the collector array parameters. As far the component parameters are verified, the long-term prediction of the system gain as well as the detection of possible sources of system malfunctioning are possible.

Annex D describes a procedure for long-term monitoring as a part of the supervision of a large custom built solar heating system. The objectives of supervision may be: a) the early recognition of possible failures of system components, in order to get the maximum benefit from the initial solar investment as well as to minimize the consumption of non-solar energy and the resulting environmental impact; b) the measurement of system performance (solar gains or other system indicators), if requested by a contractual clause, e.g. guaranteed results. The long-term monitoring in Annex D is limited to the solar energy specific aspects, especially to the determination of the solar contribution to the total heat load. Instrumentation used in the long-term monitoring should be an integrating part of the system, a part included from the very beginning of the design process. If adequately foreseen, it may also be used for system adjustment at start time.

Drinking water quality

In respect of potential adverse effects on the quality of water intended for human consumption, caused by the product covered by this standard:

a) This standard provides no information as to whether the product may be used without restriction;

b) It should be noted that, while awaiting the adoption of verifiable criteria, existing national regulations concerning the use and/or the characteristics of this product remain in force.

Factory Made and Custom Built solar heating systems

The standards KS 1852-1 as well as KS 1852-2 and the standards KS 1855-1 to KS 1855-3 distinguish two categories of solar heating systems: **Factory Made** solar heating systems and **Custom Built** solar heating systems. The classification of a system as Factory Made or Custom Built is a choice of the final supplier, in accordance with the following definitions.

Factory Made solar heating systems are batch products with one trade name, sold as complete and ready to install kits, with fixed configurations. Systems of this category are considered as a single product and assessed as a whole. If a Factory Made Solar Heating System is modified by changing its configuration or by changing one or more of its components, the modified system is considered as a new system for which a new test report is necessary. Requirements and test methods for Factory Made solar heating systems are given in KS 1852-1 and KS 1852-2.

Custom Built solar heating systems are either uniquely built, or assembled by choosing from an assortment of components. Systems of this category are regarded as a set of components. The components are separately tested and test results are integrated to an assessment of the whole system. Requirements for Custom Built solar heating systems are given in KS 1855-1; test methods are specified in KS 1855-2 and KS 1855-3. Custom Built solar heating systems are subdivided into two categories:

— **Large Custom Built systems** are uniquely designed for a specific situation. In general HVAC engineers, manufacturers or other experts design them.

— **Small Custom Built systems** offered by a company are described in a so-called assortment file, in which all components and possible system configurations, marketed by the company, are specified. Each possible combination of a system configuration with components from the assortment is considered as one Custom Built system.

Table 1 shows the division for different system types:

Table 1 — Division for factory made and custom built solar heating systems

Factory Made Solar Heating Systems (KS 1852-1, -2)	Custom Built Solar Heating Systems (KS 1855-1, -2, -3)
Integral collector-storage systems for domestic hot water preparation	Forced-circulation systems for hot water preparation and/or space heating, assembled using components and configurations described in a documentation file (mostly small systems)
Thermosiphon systems for domestic hot water preparation	
Forced-circulation systems as batch product with fixed configuration for domestic hot water preparation	Uniquely designed and assembled systems for hot water preparation and/or space heating (mostly large systems)

NOTE 1 Forced circulation systems can be classified either as Factory Made or as Custom Built, depending on the market approach chosen by the final supplier.

NOTE 2 Both Factory Made and Custom Built systems are performance tested under the same set of reference conditions as specified in Annex B of KS 1852-2 and Annex A of KS 1855-2. In practice, the installation conditions may differ from these reference conditions.

NOTE 3 A Factory Made system for domestic hot water preparation may have an option for space heating, however this option should not be used or considered during testing as a Factory Made system.

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Thermal solar systems and components — Custom built systems — Part 2: Test methods

1 Scope

This Kenya Standard applies to small and large custom built solar heating systems with liquid heat transfer medium for residential buildings and similar applications, and gives test methods for verification of the requirements specified in KS 1855-1.

This Kenya Standard includes also a method for thermal performance characterization and system performance prediction of small custom built systems by means of component testing and system simulation.

Furthermore, the Kenya Standard contains methods for thermal performance characterization and system performance prediction of large custom built systems.

This Kenya Standard applies to the following types of small custom built solar heating systems:

- systems for domestic hot water preparation only;
- systems for space heating only;
- systems for domestic hot water preparation and space heating.

This Kenya Standard applies to large custom built solar heating systems, primarily to solar preheat systems, with one or more storage vessels, heat exchangers, piping and automatic controls and with collector array(s) with forced circulation of fluid in the collector loop.

This Kenya Standard does not apply to:

- systems with a store medium other than water (e.g. phase-change materials);
- systems for space heating with a distribution fluid other than water for the space heating subsystem (e.g. air systems);
- small custom built systems with a circulation line entering any store having a feedback on the solar heated store.

Principally, systems with circulation line may be tested in accordance to the methods described in this Kenya Standard, if the connecting port for the circulation line is kept closed during the tests. This should, however, stated in the test report.

- thermosiphon systems;
- integral collector-storage (ICS) systems.

The test procedure of Annex C cannot be applied to solar heating systems with concentrating collectors.

NOTE The two test methods presented in annex C ("Short-term system testing") have only been validated, so far, two laboratories, at the Danish Technological Institute DTI and at the Chalmers University of Technology Goteborg ([9], [14]). DTI is confident that the procedures are promising and very efficient. However, the full verification and a round robin test within Europe are urgently needed.

2 Normative references

The following referenced documents are indispensable for the application of this Kenya Standard. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 806-1, *Specifications for installations inside buildings conveying water for human consumption — Part 1: General*

ISO 15783, *Seal-less rotodynamic pumps — Class II — Specification*

ISO 9906, *Rotodynamic pumps — Hydraulic performance acceptance tests — Grades 1 and 2*

EN 1717, *Protection against pollution of potable water in drinking water installations and general requirements of devices to prevent pollution by backflow*

ISO 6612, *Windows and door height windows — Wind resistance tests*

ISO 16528, *Boilers and pressure vessels*

KS 1851-1, *Thermal solar systems and components — Solar collectors — Part 1: General requirements*

KS 1851-2, *Thermal solar systems and components — Solar collectors — Part 2: Test methods*

KS 1852-1, *Thermal solar systems and components — Factory made systems — Part 1: General requirements*

KS 1852-2, *Thermal solar systems and components — Factory made systems — Part 2: Test methods*

KS 1855-1, *Thermal solar systems and components — Custom built systems — Part 1: General requirements*

KS 1855-3, *Thermal solar systems and components — Custom built systems — Part 3: Performance characterization of stores for solar heating systems*

IEC 60335-1, *Safety of household and similar electrical appliances — Part 1: General requirements*

IEC 60335-2-21, *Safety of household and similar electrical appliances — Part 2: Particular requirements for storage water heaters*

ISO 9459-5, *Solar heating — Domestic water heating systems — Part 5: System performance by means of whole system testing and computer simulation*

ISO 9488, *Solar energy — Vocabulary*

3 Terms and definitions

For the purposes of this Kenya Standard, the terms and definitions given in ISO 9488 and ISO 9459-5 as well as KS 1851-1, KS 1852-1 and KS 1855-1 apply.

4 Symbols and abbreviations

a_l	algebraic constant for the determination of the collector heat loss coefficient
A_c	collector reference area
C_c	collector array heat capacity

f_{sol}	solar fraction
G	solar irradiance
G_d	diffuse irradiance
G_g	global irradiance (i.e. horizontal)
G_h	hemispherical irradiance, e.g. on tilted plane
H_c	hemispherical solar irradiation in collector plane
$K_{\alpha\tau}$	incidence angle modifier
P_{aux}	power of the auxiliary heater
P_c	thermal power of the collector or collector array
P_{rc}	circulation heat loss power
Q_{sol}	heat delivered by the collector loop to the store
Q_{aux}	net auxiliary energy demand of a solar heating system delivered by the auxiliary heater to the store or directly to the heat distribution system (see 7.5.3)
Q_L	energy delivered at the outlet of the solar heating system
Q_d	heat demand
Q_l	store heat losses
Q_{ohp}	heat diverted from the store as active overheating protection, if any
Q_{par}	parasitic energy (electricity) for the collector loop pump(s) and control unit
$\vartheta_{average}$	yearly average cold water temperature on reference location
$\vartheta_{c,mb}$	collector ambient air temperature
$\vartheta_{s,amb}$	store ambient air temperature
$\vartheta_{ci/co}$	collector or collector array inlet/outlet fluid temperature
ϑ_{cw}	mains water temperature
ϑ_d	desired hot water temperature
ϑ_m	mean collector fluid temperature; $\vartheta_m = (\vartheta_{ci} + \vartheta_{co}) / 2$
ϑ_{rci}	fluid temperature at circulation loop inlet
ϑ_{rce}	fluid temperature at circulation loop outlet
θ_{req}	required temperature for sensor high-temperature resistance (see annex B)

ϑ_S	store outlet fluid temperature
θ_{sens}	sensor temperature (see annex B)
$\vartheta_{start/stop}$	temperature for which controller operation starts/stops (see annex B)
ϑ_{tank}	temperature of the storage tank (see annex B)
T^*	reduced temperature of collector; $T^* = (\vartheta_m — \vartheta_{c,amb}) / G_h$
$(UA)_{hx}$	heat transfer rate of a heat exchanger
$(UA)_S$	store heat loss rate
U_L	overall heat loss coefficient of collector array
V_d	demanded (daily) load volume
V_S	store volume
V_C	volume flow rate in collector loop
V_{rc}	volume flow rate in circulation loop
V_s	volume draw-off flow rate from storage
v	surrounding air speed
$\Delta\vartheta$	temperature difference
$\Delta\vartheta_{amplit}$	average amplitude of seasonal variations on reference location
η	zero-loss collector efficiency (efficiency at $T^* = 0$)

5 System classification

See clause 5 of KS 1855-1.

6 Test methods

Subsequent test methods refer to the requirements given in KS 1855-1.

NOTE The numbering of the following clauses is kept in direct correspondence to the numbering in KS 1855-1.

6.1 General

6.1.1 Suitability for drinking water

See EN 806-1.

6.1.2 Water contamination

For small custom built systems see EN 1717.

Large custom built systems: Check the hydraulic scheme or any other part of the documentation of the system according to 6.7.3 of KS 1855-1. (See also the introduction about water quality).

6.1.3 Freeze resistance

See 5.1 of KS 1852-2.

6.1.4 Overheating protection

6.1.4.1 Scald protection

If the temperature of the domestic hot water in the system can exceed 60 °C, check the design plan or the system documentation to see whether the system is provided with an automatic cold water mixing device or any other device capable for limiting the water temperature to 60 °C at most.

6.1.4.2 Overheating protection of materials

Ensure by checking the hydraulic scheme and/or by calculation and taking into account the most adverse conditions for the materials of all parts of the system, that the maximum temperatures which may occur do not exceed the maximum permissible temperatures for the respective materials.

NOTE Both transients (high-temperature peaks of short duration) and stagnation of longer duration may create adverse conditions for the respective material.

6.1.5 Reverse flow prevention

Check the hydraulic scheme included in the documentation (see 6.7) to ensure that no unintentional reverse flow will occur in any hydraulic loop of the system.

6.1.6 Pressure resistance

See ISO 16528.

If any component of the system is not covered by ISO 16528 or KS 1851-1, check the technical data to see whether the component for the part of the system in which it is used will withstand the lowest of the following pressures

- 1.5 times the manufacturer's stated maximum working pressure
- the manufacturer's stated maximum test pressure

In addition, for large custom built systems only:

- Regarding safety valves, check the hydraulic scheme or any other part of the documentation of the system according to 6.7.3 of KS 1855-1.
- Regarding pressure resistance, check whether the collector array can withstand short and high pressure peaks. Calculate the highest pressure that can occur in the individual loops in the system and compare it with the maximum allowed pressure of the individual loops (see also NOTE 2 in 6.1.6 of KS 1855-1). Alternatively, an experimental test with 1,3 times the maximum allowed pressure of each loop may be applied.

6.1.7 Electrical safety

See IEC 60335-1 and IEC 60335-2-21.

6.2 Materials

Check the work certificates provided by the manufacturer whether the requirements on UV radiation and weather resistance as well as on the choice of materials for the collector loop are fulfilled. For small custom built systems this check shall in any case be performed, for large ones as far as applicable.

6.3 Components and pipework

6.3.1 Collector and collector array

The collector shall be tested according to KS 1851-2.

In addition, the maximum disparity of the mass flow rate in parallel collector rows should be calculated by means of the corresponding pressure drops.

6.3.2 Supporting frame

Check the calculation proving the resistance of the frame to wind loads in accordance with ISO 6612.

6.3.3 Collector and other loops

The optional collector loop test comprises the following steps:

- Determination of the nominal power needed by the collector loop pump
- Calculation of the highest heat power which can be delivered by the collector array $P_{c,max}$:

$$P_{c,max} = \eta_0 A_c G_{ref} \quad (1)$$

where G_{ref} is the reference irradiance of 1000 W/m^2 (for other symbols see Clause 4).

- Check of the values calculated by formula (1) in comparison with the values listed in Table 4 of KS 1855-1.

For other heat transfer loops, the nominal parasitic power of their pump(s) should be directly compared with the calculated highest transmitted heat power, based on Table 4 of KS 1855-1.

6.3.4 Circulation pump

See ISO 9906 and ISO 15783.

6.3.5 Expansion vessel

For drain-back systems without a separate expansion vessel, check both by calculation and the hydraulic scheme to see whether the drain-back facility is able to fulfil its additional task as an expansion vessel.

6.3.5.1 Open expansion vessel

Check the volume and design of the open expansion vessel by calculation and by checking the hydraulic scheme.

In addition, check the connection of the vessel to the atmosphere, the spill line and the expansion lines on the hydraulic scheme.

6.3.5.2 Closed expansion vessel

For small custom built systems only: Check the fulfilment of the requirements given in 6.3.5.2 of KS 1855-1 by calculation and by visual check of the hydraulic scheme and operating instruction.

6.3.6 Heat exchangers

Apart from the tests in compliance with ISO 16528, check the design of the heat exchanger(s) with respect to scaling or the availability of cleaning facilities.

In addition, the drop in system efficiency $\Delta\eta$ induced by a heat exchanger in the collector loop of a small custom built system should be estimated by formula (2):

$$\Delta\eta = \frac{\eta_0 A_C a_1}{(UA)_{hx}} \times 100\ \% \qquad (2)$$

where η_0 and a_l, are given from the collector performance test of KS 1851-2. For small systems $(UA)_{hx}$ is delivered by the store performance test of KS 1855-3 ($(UA)_{hx}$ to be chosen for fluid temperatures of 20 °C). For large systems $(UA)_{hx}$ is taken from the heat exchanger performance data sheet provided by the manufacturer.

NOTE 1 In the latter case, since performance data of external heat exchangers (which are mostly used in large custom built systems) are generally quite reliable, no additional measurements are needed.

For heat exchangers in other loops (e.g., a load side heat exchanger), the mean temperature rise on the primary side $\Delta\vartheta$ which is induced by the presence of the heat exchanger should be estimated by calculation. The drop in efficiency may then be estimated by:

$$\Delta\eta = (a_l\ \Delta\vartheta / G_{ref}) \times 100\% \qquad (3)$$

where the reference irradiance G_{ref} is set to 1000 W/m^2.

NOTE 2 More accurate calculation methods are given in [1]. In special cases the thermal stratification in the store should be taken into account, to obtain an accurate figure for the efficiency drop.

6.3.7 Store

With the exception of the heat loss rate, stores for drinking water shall be tested according to ISO 16528. For small custom built systems, this test applies in any case, for large custom built systems as far as applicable.

In addition, for small custom built systems only:

- the performance of their hot water stores should be characterized according to KS 1855-3.
- the heat loss rate of these hot water stores, obtained from performance characterization according to KS 1855-3, should be compared with the requirements given in 6.3.7 of KS 1855-1.

6.3.8 Pipework

Check the design plan, manufacturer's works certificates and system documentation in respect of design and material of pipes and fittings.

6.3.9 Thermal Insulation

Check the design plans and system documentation.

6.3.10 Control system

6.3.10.1 Controller

For small custom built systems only: The optional controller test is described in annex B.

6.3.10.2 Temperature sensors

The design plans and components shall be visually checked in respect of location, installation and insulation of the sensors according to the requirements in 6.3.10.2 of KS 1855-1.

Additionally:

- For small custom built systems: Test the sensor resistance to high temperature as described in B.3. This test is, however, not necessary if a documentation delivered with the sensor indicates that it can withstand 100 °C or stagnation conditions (whichever the greatest) without altering by more than 1 K.
- For large custom built systems: Check the suitability of the temperature sensors in respect of stagnation conditions or maximum temperatures in connection with the quality declaration given by the supplier.

6.4 Safety equipment and indicators

6.4.1 Safety valves

Check the design plan and the system documentation to verify that each collector or group of collectors is fitted with at least one suitable safety valve.

Check the specification of the safety valves, whether the materials fulfil the requirements given in 6.4.1 of KS 1855-1.

Check whether the size of the safety valve is correct, in compliance with the requirements given in 6.4.1 of KS 1855-1.

Check whether the temperature of the heat transfer medium at the release pressure of the safety valve exceeds the maximum allowed temperature of the heat transfer medium.

Additionally, for large custom built systems: For testing the system behaviour after release of one or more safety valves according to the requirements given in 6.4.1 of KS 1855-1, check the electric and hydraulic schemes or any other part of the documentation according to 6.7.3 of KS 1855-1.

6.4.2 Safety lines and expansion lines

Check the hydraulic scheme and system documentation to verify that safety and expansion lines cannot be shut-off.

Check the internal diameter of the safety and the expansion line with respect to the requirements given in 6.4.2 of KS 1855-1.

Check the hydraulic scheme and system documentation to verify that the expansion line and the safety line are connected and laid in such a way that any accumulation of dirt, scale or similar impurities are avoided.

6.4.3 Blow-off lines

Check the hydraulic scheme and system documentation to verify that the blow-off lines fulfil the requirements given in 6.4.3 of KS 1855-1.

6.4.4 Store shut-off valve

For large systems only: Verify the existence of a shut-off valve by checking the system documentation in accordance with 6.7.3 of KS 1855-1.

6.4.5 Indicators

6.4.5.1 Indicators for collector loop flow

Check the hydraulic scheme and system documentation in respect of the position and installation of the recommended indicators for the collector loop flow.

6.4.5.2 Pressure gauge

Check the hydraulic scheme and system documentation in respect of the position and the installation of the pressure gauge or, in the case of some drain-back systems without pressure gauge, of the other means provided for checking drain-back and the fluid level in the collector loop.

6.4.5.3 Heat meter

If the collector loop of a large custom built system is equipped with a heat meter (see 6.4.5.3 of KS 1855-1), this should be mentioned in the system documentation.

6.5 Installation

Check the design plans and the system documentation to see whether the leak tightness of the roof may be affected by the installation of the collector.

6.5.1 Lightning

For small custom built systems see 5.5 of KS 1852-2.

For large custom built systems verify the compliance with the requirements given in 6.5.1 of KS 1855-1 by checking the documentation included in 6.7.3 of KS 1855-1.

6.5.2 Wind loads

See ISO 6612. Moreover, check the documents for the installer whether they comply with 6.5.2 of KS 1855-1.

6.6 Initial operation, inspection and commissioning

This clause applies to large systems only.

Before initial operation:

- Check whether the system layout and components are as described in the documentation.
- Check the record of the adjustments for the corresponding fittings. For each fitting a recorded adjustment shall exist.
- If there is a supervisor of the system, ensure that he has been sufficiently instructed.

The procedure for short-term system testing referred to in 6.6 of KS 1855-1 (only if needed or required) is given in annex C.

The procedure for long-term system monitoring referred to in 6.6 of KS 1855-1 (only if needed or required) is given in annex D.

6.7 Documentation

Check all documents, as to whether they fulfil the requirements given in 6.7 of KS 1855-1 and whether they are complete and understandable.

6.8 System performance

This clause applies to small systems only.

The optional performance test methods for small custom built systems are described in Clause 7. The test results shall be presented in a test report as described in clause 8.

7 Optional performance test of small custom built solar heating systems

The test method is based on component tests of the solar collector, the store(s), the controller and other components as necessary. These component tests are described in 7.1, 7.2 and 7.3. The whole system is then simulated using a validated simulation program as described in 7.4. The long-term performance of the whole system is predicted for reference conditions as described in 7.5.

If the carrying out of this performance test is required, the specification included in 7.4 and 7.5 shall be adhered to.

In general, the system does not need to be installed as a whole for testing.

For systems for hot water preparation only (class A) the full tests should be carried out including the long-term performance prediction for reference conditions.

For systems for space heating only (class B) and systems for combined domestic hot water preparation and space heating (class C) the components should be tested and the results be stated in the test report. The long-term performance prediction is a further option. If the performance prediction is carried out, the results should be stated in the test report stating also the chosen boundary conditions for the simulation. The following remark should be added to the results of performance predictions for systems of class B and C:

Intercomparison of the results of the long-term performance prediction is only possible, if validated simulation models and the same boundary conditions are used.

NOTE 1 The procedure for space heating systems as described above allows national solutions with respect to the definition of reference conditions. This is a preliminary step for the standardization of this procedure within the CEN countries. After enough experience has been gained on national level, the reference conditions for all CEN countries can be elaborated.

Before starting the performance testing all tests specified in 6.1 to 6.7 shall be completed. In case a system fails one or more of these tests, the malfunction or defect shall be eliminated by the manufacturer prior to performance testing. If this is not possible

- the malfunction shall be stated in the performance test report,
- the performance of the system shall be determined with the method as described in this clause. However, the reduction of the system performance induced by the malfunction or defect shall be estimated and the results of the performance test corrected accordingly.

NOTE 2 If the system fails one of the following tests described in clause 6, a significant reduction of the system performance can be expected:

- Collector array: balanced flow (see 6.3.1)
- Temperature sensors: thermal contact of the sensors to the part of which the temperature is measured (see 6.3.10.2)
- Reverse flow prevention (see 6.1.5)
- Thermal insulation (see 6.3.9)

7.1 Separate test of the solar collector

For the collector test according to KS 1851-2, all data for dynamic simulation of the thermal behaviour of the collector as listed below should be determined:

- standard steady-state parameters

- collector heat capacity
- incidence angle modifier for beam and diffuse irradiance
- wind speed dependence of the collector heat loss coefficients (for collectors with non-selective absorbers or unglazed collectors)
- influence of flow rate if relevant
- influence of collector tilt angle if relevant

If a solar collector is offered in different dimensions, the performance parameters of the smallest unit may be used as representative for the whole series of collectors.

7.2 Separate test of the hot water store

The store should be tested in accordance with KS 1855-3. Thereby all data for dynamic simulation of the thermal behaviour of the store as described in KS 1855-3 should be determined.

7.3 Separate test of the control system

The control system should be tested according to the methods described in annex B. Thereby all data for dynamic simulation of the behaviour of the control system as described in annex B should be determined.

7.4 System simulation model

The modelling of the system should be carried out using a detailed transient simulation programme in which it is possible to model the different system and store configurations involved, and in which all parameters determined in the component tests can be adjusted.

NOTE 1 The level of detail needed for most system types is similar to that used in the programmes TRNSYS or EMGP3 or equivalent.

The component models for collector and store used in the system simulation shall be respectively the same as for the characterization of the collector according to KS 1851-2, and for the characterization of the store according to KS 1855-3. The store model shall be able to adequately simulate thermal stratification in the store.

The control concept tested according to annex B shall be included in the simulation programme.

For other components, e.g. pipework or external heat exchanger, the level of detail in the simulation model shall correspond to the available technical data.

The following features shall be implemented in the model:

NOTE 2 The computation of the irradiance on the tilted plane should be as detailed as possible. Up-to-date models and any simplified tools should be avoided. A radiation model is given in [2], [3,] [4], and [5]. (See Bibliography.)

- A thermostat mixer which reduces the store outlet temperature i9s to the desired temperature $, during draw-offs. For solar preheat systems and solar-only systems this thermostat mixer shall be located directly at the outlet of the solar part of the system.
- The collector loop operation shall be stopped when the store temperature exceeds 100 °C if no other temperature is specified by the manufacturer.

The system simulation model shall have been previously validated.

7.5 Long-term performance prediction

The recommended long-term system performance prediction is described only for system class A (domestic hot water preparation only). However, for system classes B and C the same general principles apply.

7.5.1 Calculation procedure

Use the simulation model selected according to 7.4. The component parameter values used for the simulation are those given by the separate component tests according to 7.1 to 7.3. Data on other components of the system, e.g. pipework or external heat exchanger, should be used as given by the manufacturer.

The reference conditions as specified in annex A shall be used when calculating or reporting the performance of a system by computer simulation.

7.5.2 Prediction of yearly system performance indicators

NOTE In the following paragraphs, performance indicators for solar heating systems for hot water preparation only are specified. The text of these paragraphs is identical for this Kenya Standard and for Factory Made Systems (KS 1852-2), except that the calculation of the performance indicators is mandatory for Factory Made Systems, being, on the contrary, optional here. Performance indicators for space heating systems are presently excluded, since there is not yet enough experience available. This is a preliminary step for the standardization of this procedure. After enough experience has been gained, the performance indicators for space heating systems will be determined.

Uniform reference conditions for the calculation of the performance are specified in the identical annexes, Annex A of this standard or Annex B of KS 1852-2. For these conditions, the following performance indicators should be derived from the performance test results:

For solar-plus-supplementary systems:

- the net auxiliary energy demand $Q_{\text{aux, net}}$
- the parasitic energy Q_{par}

For solar-only and preheat systems:

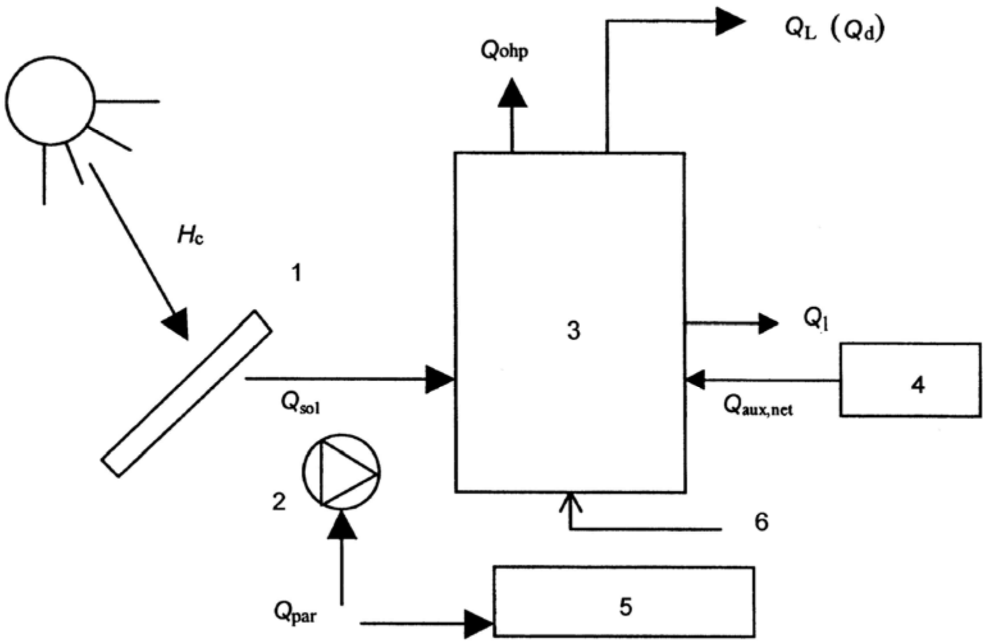
- the heat delivered by the solar heating system Q_{L}
- the solar fraction f_{sol}
- the parasitic energy Q_{par} if any

7.5.3 Calculation of the net auxiliary energy demand for solar-plus-supplementary systems

Calculate the yearly net auxiliary energy demand $Q_{\text{aux,net}}$ directly by computer simulation (long-term performance prediction) as specified in 7.5.1 of this Kenya Standard (for Custom Built Systems) or 5.9.3.2 of KS 1852-2 (for Factory Made Systems). Additional indication to the quantities entering the energy balance of one-store and two-stores solar-plus-supplementary heating systems is given in Figure 1.

If a solar-plus-supplementary system cannot meet the heat demand to such a degree that the energy delivered to the user is less than 90 % of the yearly heat demand, this should be stated in the test report.

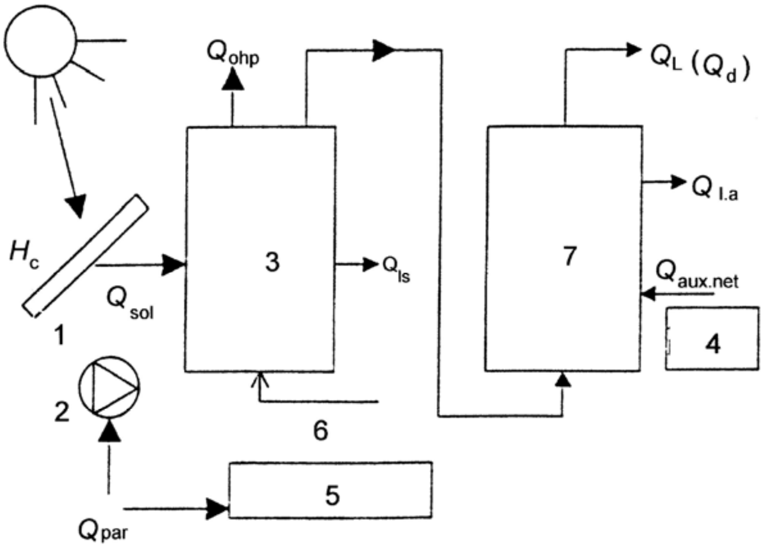
NOTE The energy delivered to the user can be less than the heat demand for example when the power of the auxiliary heater is not sufficient or when strong mixing occurs in the store during draw-offs.



Key

1 Collector	4 Auxiliary heater
2 Pump	5 Control Unit
3 Store	6 Cold Water

a) Energy balance for one-store solar-plus-supplementary systems



Key

1 Collector	4 Auxiliary heater	
2 Pump	5 Control Unit	
3 Solar Store	6 Cold Water	7 Auxiliary store

b) Energy balance for two-store-solar-plus-supplementary systems

Figure 1 — Energy balance for one-store and two-stores solar-plus-supplementary systems

7.5.4 Calculation of the solar fraction for solar-only and preheat systems

Compute the system energy balance on a yearly basis. This includes the following energy quantities (see Figure 2 and Figure 3), calculated using the reference data and conditions given in annex A of this Kenya Standard or Annex B of KS 1852-2

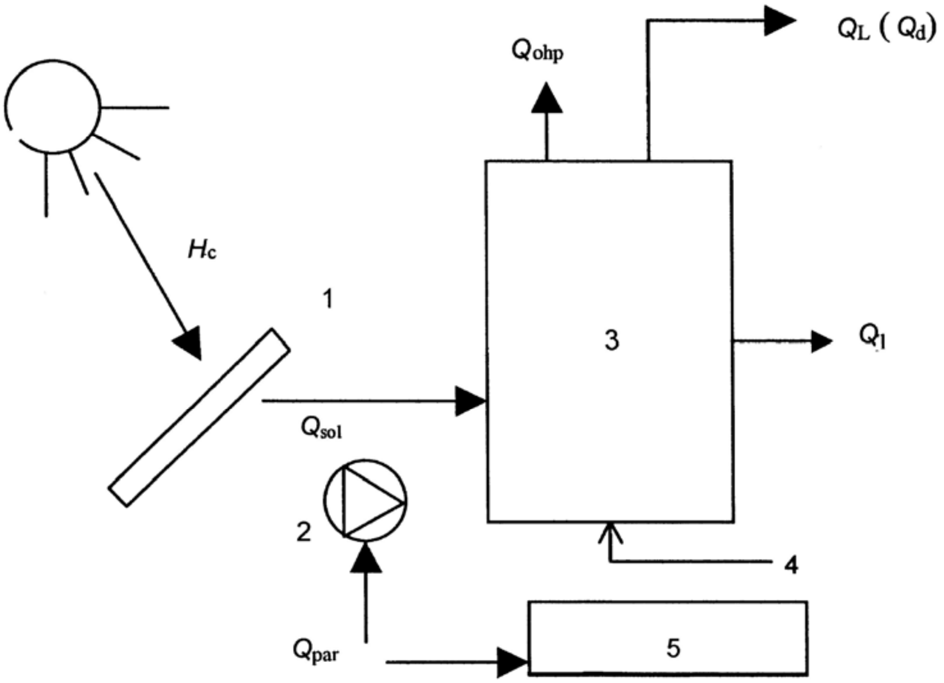
Q_d	heat demand;
Q_L	heat delivered by the solar heating system (load)
Q_{par}	parasitic energy (electricity) for pump and controls;

The parasitic energy Q_{par} shall be calculated according to 7.5.5

NOTE 1 The reference location for calculating the load Q_L are the store ports or the load-side heat exchanger ports, if provided. The reference temperature for calculating the loads is the cold water temperature. Heat losses of the circulation line, if any, are not included in the loads, as the test is carried out with this line kept closed.

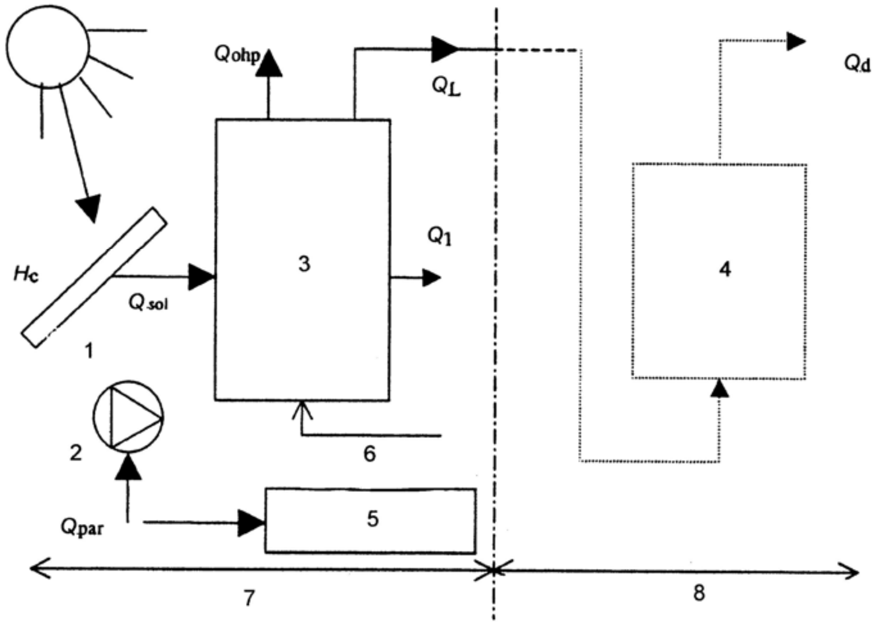
NOTE 2 According to ISO 9488, a solar preheat system is a solar system to preheat water or air prior to its entry into any other type of water or air heater. This water or air heater is not part of the solar preheat system itself. Hence, for this type of system the energy delivered by the solar heating system Q_L is calculated at the outlet of the solar heating system and the store heat loss Q_L is the heat loss of the solar store itself (see Figure 3).

NOTE 3 The yearly heat demand is calculated using the load volume, cold water temperature and the desired temperature for hot water as specified in annex A.



Key
1 Collector
2 Pump
3 Store
4 Cold water
5 Control unit

Figure 2 — Energy balance for solar-only systems



Key
1 Collector
2 Pump
3 Solar store
4 Auxiliary heater
5 Control unit
6 Cold water
7 Solar preheated system
8 Series-connected auxiliary heating system

Figure 3 — Energy balance for solar preheat systems

Calculate the solar fraction, f_{sol} by using the definition of ISO 9488:

Solar fraction, f_{sol}: The energy supplied by the solar part of a system divided by the total system load (Q_d = heat demand).

$$f_{sol} = Q_L/Q_d$$

7.5.5 Calculation of the parasitic energy

Calculate the yearly parasitic energy Q_{par} needed by pumps, controllers etc, in conformity with 4.6.3 h) 3) of KS 1852-1.

7.6 Presentation of performance indicators

The results from 7.5.1 to 7.5.5 should be presented for the load volume(s) as specified in Annex A in the way shown in Table 2 and Table 3.

Table 2 — Presentation of system performance indicators for solar-plus-supplementary systems

Performance indicators for solar-plus-supplementary systems on annual base for a volume demand of .... l/d			
Location (latitude)	Q_{d} MJ	$Q_{\text{aux, net}}$ MJ	Q_{par} MJ
Stockholm (69.6° N)	.....		
Würzburg (49.5° N)	.....		
Davos (46.8° N)			
Athens (38.0° N)	.....		
……. [1]			
[1] For a location free to choose			

Table 3 — Presentation of system performance indicators for solar-only and solar preheat systems

Performance indicators for solar-only and solar preheat systems on annual base for a volume demad of .... l/d				
Location (latitude)	Q_{d} MJ	Q_{l} MJ	f_{sol} %	Q_{par} MJ
Stockholm (69.6° N)				
Würzburg (49.5° N)	.....			
Davos (46.8° N)	.....			
Athens (38.0° N)				
…… [1]				
[1] For a location free to choose				

8 Performance test report

This clause describes the report of results from the optional tests performed according to Clause 7. This test report applies to small custom built systems only as also the system performance test methods given in Clause 7 are applicable to small custom built systems only (see 6.8).

The test report shall include:

- a detailed description of components and system configuration
- the prediction method used. The simulation programme shall be specified and an input file shall be enclosed.
- the complete reference conditions used as specified in Annex A including information about the location for which the performance prediction is made and the reference weather data used.
- for the reference conditions as specified in Annex A, the performance indicators on a yearly base as specified in 7.5.2.

Annex A
(normative)

Reference conditions for performance prediction

A.1 General

The conditions given in Table A.1 shall be used when calculating, reporting or comparing the performance of a system, either from a test or from a computer simulation. These conditions should also be applied to the system during any system performance test, if not specified otherwise.

NOTE The following reference conditions are identical for testing and simulating of Factory Made Systems in KS 1852-2 and Custom Built Systems in this Kenya Standard. However, some aspects related to systems considered in only one of the two standards, have been deleted from the other standard.

Table A.1 — Reference conditions for performance presentation

Reference condition	**Value**	**Remarks**
SYSTEM		
Collector orientation	South	
Collector tilt angle	45°	For testing, (45 ± 5)° if not fixed for the system or specified by the manufacturer.
Total length of collector circuit	20m = 10m + 10m	If piping is not delivered with the system or specified by the manufacturer.
Pipe diameter and insulation thickness of collector circuit	See A.2	If piping is not delivered with the system or specified by the manufacturer.
Location of the collector circuit pipes	Indoors, for systems with the store located indoors; outdoors, for systems with the store located outdoors	As far as possible at the test rig
Store ambient temperature	15 °C	For systems where the store is located outside, the ambient temperature from the climate shall be used.
For systems with indirect (hydraulic) auxiliary heating: Power to be applied on auxiliary heat exchanger	(100 ± 30) W per liter of store volume above the lowest end of heat exchanger	If the auxiliary heater is not delivered with the system and no restrictions have been given in the documentation. The auxiliary heater shall be modeled as an ideal heat source with no heat capacity and constant heating power.
Flow rate through auxiliary heat exchanger		The flow rate through the heat exchanger shall be chosen such that the temperature difference between the inlet and outlet of the auxiliary heat exchanger is (10 ± 2) K under steady state conditions, unless specified otherwise by the manufacturer.

(continued)

Table A.1 (continued)

For systems with electrical auxiliary heating: Power of electrical element	If an electrical element is normally delivered with the system or specified by the manufacturer, this element shall be used. Otherwise, (25 ± 8) W per liter of store volume above the electrical element apply.	
For solar-plus-supplementary systems: Status of the auxiliary heater	Permanently activated	This is for performance prediction
Temperature of integrated auxiliary heating	52,5 °C (minimum temperature of hysteresis)	Or a higher temperature, if recommended by the manufacturer
CLIMATE		
Reference locations	Stockholm, Würzburg, Davos, Athens	In the reporting form, the performance of a different location of choice may also be given.
Climate Data	For Stockholm: CEC Test Reference Year; for Davos, Würzburg and Athens: Test Reference Year.	
HEAT LOAD		
Daily load pattern	For all systems: - 100 % at 6 h after solar noon For testing, the load patterns shall be as specified in the test procedure.	
Cold water supply temperature	See A.3	For testing, the temperature shall be as specified in the test procedure
Desired (mixing valve) temperature	45 °C	If the daily or yearly loads are calculated in terms of energy, this energy shall be calculated using the cold water supply temperature and the desired temperature.
Daily load volume	The load volumes in liters per day shall be chosen from the following series: 50 l/d, 80 l/d, 110 l/d, 140 l/d, 170 l/d, 200 l/d, 250 l/d, 300 l/d, 400 l/d, 600 l/d. If larger loads are required, the series may be extended by repeatedly multiplying by the square root of 2 and rounding to the nearest multiple of 10.	
	The manufacturer shall give a design load for the system. The nearest value given in the above series shall be used, as well as the next lower and higher values. It is recommended to use all lower and higher values from the series, which lie between 0.5 and 1.5 times the design load. NOTE fixed load volumes have been chosen to facilitate comparison of the performance of different systems. For testing, the load volumes as specified in the test procedures shall be used.	

A.2 Pipe diameter and insulation thickness

If the pipe and insulation for the collector circuit are delivered with the system, or the pipe diameter and the insulation thickness to be used for the collector circuit are clearly specified in the installation manual for the system, the delivered hardware or the specified values shall be used.

When piping and insulation are not delivered with the system or clearly specified, the pipe diameter, the pipe thickness and the insulation thickness given in Table A.2 shall be used for forced-circulation systems.

The material for the collector circuit piping shall be copper, unless specified otherwise in the installation manual.

Table A.2 — External pipe diameter and insulation thickness for forced-circulation systems

Flow rate in collector circuit l/h	External pipe diameter[1]) mm	Pipe thickness mm	Thickness of one layer insulation[2]) mm
<90	10	1	20
90 - 140	12	1	20
140-235	15	1	20
235 - 405	18	1	20
405 - 565	22	1	20
565 - 880	28	1.5	30
880 - 1445	35	1.5	30
1445 - 1500	42	1.5	39
> 1500	Such that the flow velocity is approximately 0.5 m/s	1.5	as the internal pipe diameter

[1]) Tolerance 1 mm
[2]) Tolerance 2 mm

A.3 Calculation of cold water temperature at reference location

The cold water temperature shall be calculated according to:

$$\vartheta_{CW} = \vartheta_{average} + \Delta\vartheta_{amplit}\sin(2\pi\ (Day - D_s) / 365)$$

where

ϑ_{CW}	is the cold water temperature to be used for performance presentation
• $\vartheta_{average}$	is the yearly average cold water temperature on reference location
$\Delta\vartheta_{amplit}$	is the average amplitude of seasonal variations on reference location
Day	is the day number of the year
D_s	Shift term

The yearly average cold water temperature, average amplitude of seasonal cold water temperature variations and shift term given in Table A.3 shall be used for the reference locations.

Table A.3 — Data for calculation of the cold water temperature at the reference locations

Reference location	$\vartheta_{\text{average}}$ °C	$\vartheta_{\text{amplit}}$ °C	D_s d
Stockholm	8.5	6,4	137
Würzburg	12.0	3.0	137
Davos	5.4	0.8	137
Athens	17.8	7.4	137

Annex B
(normative)

Testing of solar loop controllers with temperature sensors

B.1 Purpose

The testing of solar loop controllers includes the following two partial tests:

a) Testing of capability of temperature sensors to resist high temperatures (mandatory test) to prove that a sensor installed in the solar collector will tolerate stagnation temperature, i.e. temperatures of up to 200 °C.

b) Function testing of differential thermostats (optional) to determine starting and stopping differentials in dependence on temperature level, to demonstrate that the temperature indication is correct and that the function and operation comply with the manufacturer's guidance.

Furthermore, it should be documented that starting and stopping differentials are unchanged in relation to the above statement at 6 % over nominal mains voltage, 230 V, and 10% below.

B.2 Field of application

Testing of temperature resistance in sensors can be applied to all kinds of sensors.

Function testing can be applied to differential thermostats independent of sensor type (resistance sensors or voltage supplier etc.) — the simulation box method can only be applied to resistance sensors, however.

Other types of controller systems for solar heating systems may be tested "*ad hoc*", for instance clock controllers, light sensor controllers and solar cell controllers.

NOTE Basic information is given in [11] to [13].

B.3 Testing the sensors' capability to resist high temperatures

B.3.1 Temperature requirements

The temperature requirements for the sensor depends on its application as shown in Table B.1:

Table B.1 — Temperature requirements

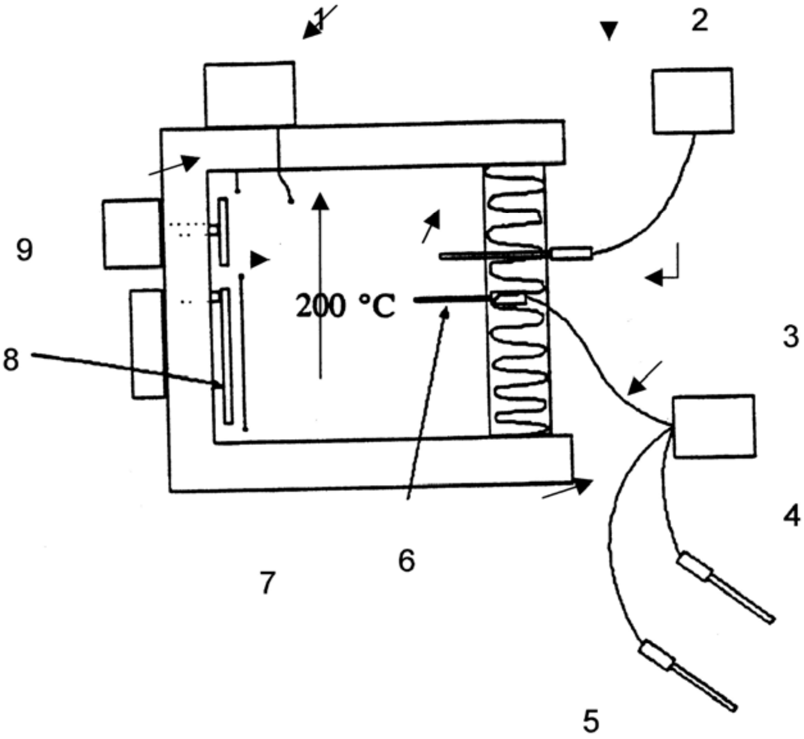
Application:	Temperature requirement:
Selective absorber with single cover	$\vartheta > 200$ °C($\vartheta_{req} = 200$ °C)
Non-selective absorber with single cover	$\vartheta > 150$ °C($\vartheta_{req} = 150$ °C)
Uncovered absorber; store sensors	$\vartheta > 100$ °C($\vartheta_{req} = 100$ °C)

B.3.2 Equipment

For the testing of the high-temperature resistance of sensors the following items shall be used (Figure B.1):

— “High temperature device”. A device able to provide a stable temperature of at least 200 °C. This could be an oven with integrated heating element and fan (see Figure B 1) a temperature bath, or a temperature calibrator.

- Temperature calibrator.
- Digital multi-meter (for voltage, current and electrical resistance measurements).



Key

1 Thermostat	6 Collector sensor
2 Sensor and control for oven temperature	7 Oven 200 °C
3 Controller	8 Heating element
4 Tank sensor	9 Fan
5 Optional: Sensor for space heating control	

Figure B.1 — **Example of oven-arrangement for sensor high-temperature resistance testing**

B.3.3 Test procedure for sensor resistance to high temperatures

The test procedure applies to sensors irrespective of the type of solar collector in which they are used.

a) Both solar collector sensor and tank sensor shall be connected electrically to the controller in accordance with the manufacturer's guidelines. The controller unit shall be connected to mains supply and put into operation. Thus the sensors are exposed to the normal sensor current with the consequent self-heating.

b) The solar collector sensor shall be placed in the temperature calibrator at 20 °C, 50 °C and 90 °C respectively. If the controller has a temperature display for the collector sensor the corresponding temperatures can be read directly from the controller display, if not the sensor shall be electrically disconnected from the controller and the corresponding resistances measured by means of an Ohm-meter.

c) The solar collector sensor shall be installed in the "high temperature device" so that the active part of the sensor is totally exposed to the high temperature and the cable will not be destroyed by the heat. The temperature of the tank sensor shall remain at 20 °C.

d) The temperature shall be increased from 20 °C to ϑ_{req} (see Table B.I).

e) The sensor shall be exposed to the temperature ϑ_{req} for 4 hours, and then the test in item b) shall be repeated.

The measured values before and after temperature influence shall be compared and the results assessed as follows:

- If the measured values after exposure differ by less than 1 K from the corresponding values before, then the sensor may be accepted.
- If the sensor does not meet the above criterion, the sensor may not be accepted.
- Besides the test of the electric function, the sensors shall be subject to a visual inspection of sensor box, gasket and cables so that any decomposition due to temperature influence can be incorporated in the test report.

B.4 Optional function testing of differential thermostats

B.4.1 Principle

The function testing at various operation situations can be performed in two ways:

- By means of a simulation box (can only be applied to resistance sensors)
- With a temperature calibrator

B.4.1.1 Simulation box approach

The test equipment comprises a custom-built simulation box, which allows the simulation of every occurring temperature sensor resistance (see Figure B.2).

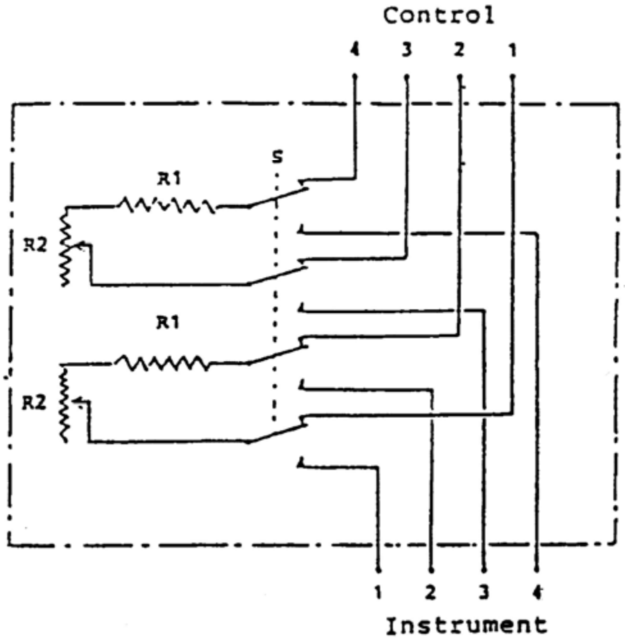


Figure B.2 — **Example of a simulation box for testing differential thermostats of solar heating systems**

In Figure B.2, S indicates a four-pole switch. In the position shown, the resistors R_1 and R_2 are connected to the control unit of the solar heating system. In the other position, these resistors are connected to a multimeter. The resistors R_1 are chosen in such a way that they correspond to the lowest resistance of the sensors under test within the test temperature range. R_2 are wire-wound multiturn potentiometers, the resistance range of which is chosen so that the resistance range of all sensors under test is covered by the potentiometers connected in series to R_1.

Hence, the differential thermostat (controller) is connected to the simulation box, so that the controlling sensors are replaced by the variable resistances of the simulation box.

In the "Simulation box" approach the test procedure is as indicated below. This procedure is related to the case for which the on- and off- temperature differences for a sensor pair (for instance a solar collector sensor and a tank sensor) are determined. In cases of testing "multifunction" controllers, each operational situation (described in the manufacturer's guidance) should be tested separately.

a) The "tank sensor resistor" is switched to the desired temperature level for the tank sensor, ϑ_{tank}; the temperature/resistance conversion takes place on the basis of the actual data sheet for the sensor type.

b) The resistance of the solar collector sensor is slowly changed corresponding to increasing temperature in the solar collector, until the pump relay of the differential thermostat turns on. The corresponding resistance is observed and converted to a "start temperature" ϑ_{start}.

c) The resistance of the solar collector sensor is slowly changed corresponding to decreasing temperature in the solar collector, until the pump relay of the differential thermostat turns off. The corresponding resistance is observed and converted to a "stop temperature" ϑ_{stop}.

d) The on- temperature difference is calculated by ϑ_{start} - ϑ_{tank} and the off-temperature difference is calculated by ϑ_{stop} - ϑ_{tank}.

The procedure is repeated with tank temperatures of 20 °C, 50 °C and 90 °C.

B.4.1.2 Temperature calibrators / temperature baths approach

The testing equipment comprises temperature calibrators or temperature baths.

The correct installation of the sensors according to the manufacturer's guidance should be checked.

In the "Temperature calibrators/temperature baths" approach the test procedure is as indicated below. This procedure is related to the case for which the on- and off- temperature differences for a sensor pair (for instance a solar collector sensor and a tank sensor) are determined. In cases of testing "multi-function" controllers, each operational situation (described in the manufacturer's guidance) should be tested separately.

a) The two temperature sensors are placed into separate temperature baths of equal temperatures. The temperature of the solar collector sensor is slowly increased according to increasing temperature in the solar collector until the pump relay of the differential thermostat turns on. The sensor temperatures i9tank (tank sensor) and i9start (collector sensor) are read. If a calibrator is used the temperature should be raised step by step by no more than 1 K respectively. After each step, temperature stability in the calibrator should be awaited. The slow increase in a temperature bath can be made continuously provided that the bath temperature is measured close to the sensor.

b) The temperature of the solar collector sensor is slowly decreased equivalent to decreasing temperature in the solar collector until the pump relay of the differential thermostat turns off. The sensor temperatures ϑ_{tank} (tank sensor) and ϑ_{stop} (collector sensor) are read.

c) The on- temperature difference is calculated by ϑ_{start} - ϑ_{tank} and the off- temperature difference is calculated by ϑ_{stop} - $\vartheta_{tank.}$

The procedure is repeated with tank temperatures of 20 °C, 50 °C and 90 °C.

B.5 Optional testing of the mains voltage dependence

B.5.1 Principle

According to temporary regulations after the revision of the IEC 60038, which states an interval of 230 V + 10 %, function testing of the differential thermostat is performed at the mains voltage of 230 V + 6 % and 230 V - 10 %.

NOTE According to information provided by IEC, the temporary regulations will be completed in the year 2003 (see DEMKO notification No 30/88).

B.5.2 Equipment

a) Mains voltage stabilization box

b) Variable AC voltage supply 0 V to 260 V/300 W at 220 V supply

c) Temperature calibrator or simulation box

d) Digital multi-meter for supervision of mains voltage level

B.5.3 Preparation of the unit

Depending on the function test according to B.4.1, the differential thermostat is connected to the simulation box, or the associate temperature sensors are installed in the temperature calibrator, correctly installed corresponding to the manufacturer's guidance.

B.5.4 Test procedure

- The variable voltage supply is connected to the mains voltage stabilization box and switched to 207 V.
- The solar loop controller is connected 1 hour before start of function testing.
- A function testing of the differential thermostat (see B.4) is performed at 3 different tank temperatures at 20 °C, 50 °C and 90 °C respectively.
- The variable voltage supply is now switched to 244 V, the control system being connected, o
- After one hour the function testing is repeated at the same 3 tank temperatures of 20 °C, 50 °C and 90 °C respectively.

Annex C
(informative)

Short-term system testing

C.1 General

The objective of short-term system testing is to estimate the long-term system performance.

A system inspection should be performed and any error detected should be corrected before the beginning of the short-term system test (see, e.g. [6]).

In principle, two approaches for short-term system testing are referred to in this Kenya Standard:

a) the check of short-term system performance;

b) a short-term test for long-term system performance prediction.

Both approaches are applicable to systems including auxiliary heating only in the case that heat contribution by auxiliary source can be measured with an accuracy of at least 5 %.

The first test method is a simplified one. A check of the system performance is carried out by comparing the measured solar heating system gain with the one predicted by simulation using the actual weather and operating conditions as measured during the short-term test.

By the second test method, performance of the most relevant components of the solar heating system is measured for a certain time period while the system is in normal operation. These detailed measurements include the energy gain of the collector array(s) and the energy balance of the store(s). Comparing the observed and simulated energy gives a validation of collector and storage design parameters and the measured data for the collector array are also used for direct identification of the collector array parameters. When the parameters of the components are verified, the long-term prediction of the system gain is enabled as well as a detection of possible sources of system malfunctioning.

C.2 Instrumentation, data acquisition and processing

C.2.1 General

This clause includes instructions and recommendations on instrumentation, data acquisition and processing to be applied if any of the measurements described in this annex is carried out.

NOTE If possible, these instructions and recommendations should be reviewed already at system design time, and used to minimize the test expenses and maximize the outcome of the test.

C.2.1.1 Location of sensors

Sensors designated to take data for irradiance, surrounding air speed and ambient air temperatures should be mounted as described in C.2.1.2 to C.2.1.7.

C.2.1.2 Pyranometer for hemispherical irradiance

The pyranometer for the measurement of the hemispherical irradiance should be installed at the same geometrical plane as the collector array. It should be installed near the upper part of the collector array. If more arrays are situated on a different orientation, the test engineer has to decide whether irradiance will be measured for each array or computed on the basis of measurements on the horizontal plane.

C.2.1.3 Pyranometer for diffuse irradiance

The pyranometer for the measurement of the diffuse solar irradiance should be installed in the same geometrical plane as the collector array. It should be installed near the upper part of the collector array in the vicinity of the pyranometer measuring hemispherical irradiance.

For collector arrays situated significantly off-south (azimuth is off-south by more than 10°) the diffuse irradiance should be measured at the horizontal plane instead of the tilted plane together with an additional pyranometer used for measuring the global irradiance (i.e. on horizontal plane). The fraction of diffuse irradiance at the tilted plane is then to be computed based on the measured fraction at the horizontal plane.

C.2.1.4 Ambient air temperature

The ambient air temperature in the vicinity of the collector array should be measured, if possible, using a shaded and ventilated sensor approximately 1 m above the array, not closer than 1.5 m to the collector array and not further away than 10m away from the array.

The sensor measuring the ambient air temperature in the vicinity of storage unit(s) should be situated in a manner to be shielded from heat radiation sources such as stores, lights, auxiliary heaters etc.

C.2.1.5 Fluid temperatures

The sensors for measuring the fluid temperature should be located as close as possible to the inlet and outlet of the collector array and respective storage loop inlet(s)/outlet(s). Mixing devices mixing the fluid before the sensor are recommended. The piping between measurement points and the collector array or the storage respectively, should be properly insulated.

NOTE Measurement accuracy increases if the sensors are so close to the array (or to the storage) that they are thermally coupled to the array (or to the storage) even when there is no fluid circulation.

C.2.1.6 Volumetric flow meter

The volumetric flow meter should directly be installed in the loop's coldest part (e.g. mains cold water line, or for the collector loop, the collector array).

The additional pressure drop introduced by the flow meter and its connecting pipes should be negligible compared to the pressure drop in the remaining of the hydraulic loop, so that the flow rate is the same with and without the flow meter.

C.2.1.7 Anemometer

The surrounding air speed should be measured on a flat surface (min. dimension: 1m × 1m) fixed in the same plane as the collector array front cover. The anemometer should be positioned at a height approximately equal to the height of the centre of the collector array. The height of vanes should be 15 cm above the surface to which the anemometer is mounted. The anemometer should be located as close as possible to the collector array, the distance should not exceed 1 m.

C.2.2 Accuracy and calibration of sensors

The requirements on sensor accuracy stated in ISO 9459-5 should be fulfilled and the calibration procedures described in that standard should be followed.

C.2.3 Data acquisition and processing

The data specified in Table C.1 and Table C.2 should be measured and recorded by the data logger. All measured data during a test sequence should be recorded with time intervals not exceeding the values specified in Table C.1 or Table C.2.

C.3 Check of short-term system performance

C.3.1 Principle

The principle of the method is indicated in Figure C.1.

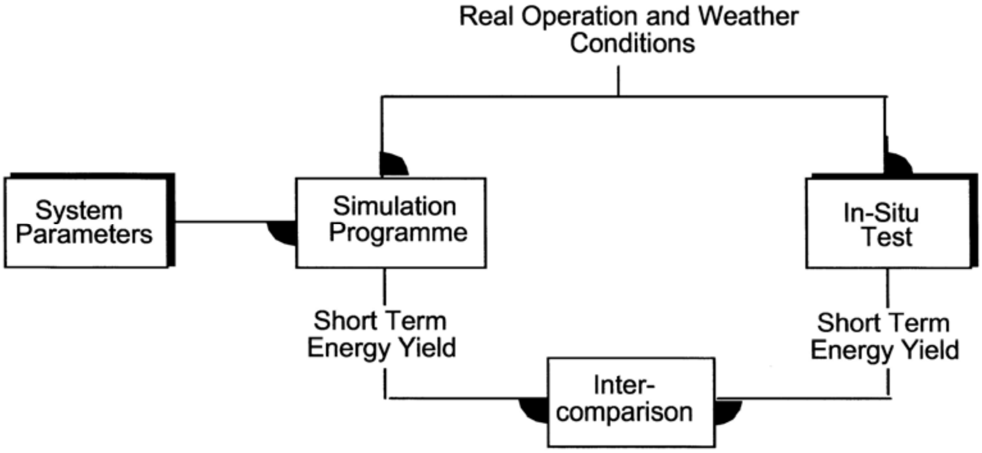


Figure C.1 — Principle of the short-term system performance check: Check and intercomparison of useful energy gain

The principle of this method is to compare the measured output of the solar heating system with the output predicted by a simulation program.

The components parameters required for simulation of system performance are derived from the system documentation or the manufacturer's data. If they are not available they can be estimated. The simulation should be carried out using weather data and solar heating system operating conditions (draw-off profile, mains water temperature, etc.) as occurred during the measuring period.

NOTE The main advantage of this method is that expensive measurements are avoided. Therefore, it is appropriate to use it for smaller systems where the cost of the test is the most critical factor.

The measurement of data as requested in C.3.2.2 should be carried out continuously until the criteria for termination of the measurement, as indicated in C.3.3, are met. The measurement should take place under "operation conditions" of the system. "Operation conditions" is defined as follows:

- For solar water heating systems: the consumer daily draw-off volume is between 50 % and 150 % of the corresponding daily draw-off volume as expected for the system and/or as predicted by the solar heating system designer.
- For solar space heating system: the solar space load is between 50 % and 150 % of the corresponding load as expected for the system under particular weather conditions and house occupancy.

This method is applicable for solar-preheat systems (e.g., systems without auxiliary energy source inside the storage) and for storage without a circulation loop.

However, the systems with auxiliary heat source and circulation loop may be treated in a similar way if the following is assured:

- The uncertainty of measurement for the auxiliary heating should be better than 2 % if immersed electrical heaters are used. For other types of auxiliary heating the uncertainty should be better than 5 %.

- The uncertainty of measurement for the heat loss power in a circulation loop should be better than 3 %.

- The circulation loop is not connected to the solar (part of the) store, hence heat from auxiliary heating cannot be transferred to the solar (part of the) store.

C.3.2 Measurement of the system energy gain

C.3.2.1 Conditioning

For the dynamic simulation of the system performance the initial energy content of the store (i.e. the mean store temperature) is one of the required inputs. As measurements inside the store should be avoided, the initial state of the store may be found by forced store conditioning or it may be estimated on the basis of fluid temperature measurements at the collector inlet (piping leaving the lower part of the storage vessel) and the draw-off inlet/outlet (for hot water heating systems).

In order to minimize the influence of the error in determination of the initial energy content of the store(s), conditioning should be performed, whenever possible, prior to the measurement sequence.

The conditioning period encompasses the withdrawal of at least 3 storage volumes. The withdrawal should be carried out by night or during day periods with low hemispherical irradiance, i.e. less than 200 W/m^2.

NOTE Due to high water costs, conditioning should be avoided whenever the initial energy status of the store can be approximately estimated — e.g. if the daily load consumption exceeds the storage volume and after several (2-3) days of proceeding measurements the daily irradiation was lower than 5 MJ/(m^2 d).

Conditioning applies only if the store volume is less than 5 m^3. If conditioning is not carried out, the initial energy state of the store(s) should be estimated using the store draw-off temperature and the collector fluid inlet temperatures by means of the particular storage model (i.e. taking into account the stratification effect).

C.3.2.2 Measurements

The measurement data indicated in Table C.1 should be continuously recorded on a data logger.

Table C.1 — Variables to be measured and corresponding maximum sampling intervals

Symbol	Unit	Variable	Maximum sampling interval s
ϑ_{cw}	°C	mains water temperature	5
ϑ_s	°C	storage draw-off temperature	5
$\dot{V}_S$	m^3/s	volume draw-off flow rate from storage	5
G_g, G_h	W/m^2	global or hemispherical irradiance	5
G_d	W/m^2	diffuse irradiance	5
$\vartheta_{c,amb}$	°C	collector ambient air temperature	30
$\vartheta_{s,amb}$	°C	storage ambient air temperature	30
P_{aux}	W	auxiliary power	5
P_{re}	W	circulation heat loss power	5
NOTE Integrating instruments should be applied for auxiliary power, circulation losses and draw-off quantities.			

C.3.3 Criteria for termination of the test

For termination of the test, the following criteria should be met:

- The irradiation integrated over the measurement sequence should be greater than 150MJ/m^2.
- At least 50 % of irradiation should occur during the time intervals with an irradiance exceeding 500 W/m^2.

Due to the possible error in estimation of the initial energy content of the store, the two first days of measurements should not be taken into account.

C.3.4 Simulation of the system useful energy gain using components data

The performance of the system can be predicted by means of a validated simulation program.

The store and collector parameters should be available in the system documentation.

If data for other system components such as piping, external heat exchanger etc. are not included in the system documentation, those data given by the manufacturer should be used. If data are not available, they may be estimated.

The performance of the system, e.g., the useful energy gain, can be predicted for weather and load conditions as observed over the monitoring period.

C.3.5 Comparison of measured with simulated data

The useful energy gain delivered by the store over the test period should be compared with the observed data on daily basis.

The solar heating system under test is considered to behave as predicted by the simulation program if the difference (on the basis of daily values) between the observed and predicted system power does not exceed 10 %.

As errors in estimation of the initial energy status of the store may occur, the first three days of measurements should not be taken into account.

The comparison on daily basis should be done only for days at which error in estimation of the initial energy status of the store at the beginning of measurement sequence may be neglected and, additionally, if the daily irradiation exceeds 15 MJ/m^2.

Finally, the difference between predicted and measured useful energy gain over the complete monitoring period (excluding the first three days as mentioned above) should not exceed 10 % in relation to the observed energy gain.

C.3.6 Test report

The test report should include the following items:

- Detailed description of components and system configuration
- Prediction method used: The simulation program used should be specified and an input file enclosed.
- Weather data and space heating load and/or hot water demand profile: The file(s) containing data concerning monitoring of the system performance should be enclosed.

- Predicted solar energy output of the solar heating system: The daily predicted output (by the simulation program) as well as the observed one should be presented by graph and table.
- List of the measuring equipment and sensors, with the corresponding accuracy
- Interpretation of possible reasons for discrepancy of the predicted and observed power

C.4 Short-term test for long-term system performance prediction

C.4.1 General

The performance of large solar hot water and/or space heating systems depends on their design parameters and on various weather and operating conditions, e.g. irradiance, ambient temperature, wind speed, and fluid inlet temperature.

In order to evaluate long-term system performance and detect sources of system malfunctioning, it is primarily necessary to

a) check the energy delivered by the collector array,

b) check the energy balance over the storage vessel(s) and, if possible,

c) identify the most important system parameters.

NOTE Ideally, both collector and storage parameters would be identified under in-situ conditions. Unfortunately, the state-of-the-art does not allow accurate and repeatable results of in-situ test of the storage vessels. Therefore, in this Kenya Standard the short-term system test is limited to the above points a) and b) and the identification of the collector array parameters only.

So, the storage simulation model is verified by checking the storage energy balance while the collector array parameters are identified directly. With the identified collector parameters and the validated storage model, both an accurate prediction of long-term system performance and a detection of sources of system malfunctioning are possible.

For more information, see [14].

C.4.2 Principle

The principle of the method is indicated in Figure C.2.

Measurement data should be collected under non-stationary operation. A wide range of operation conditions representative for the system being tested should be covered.

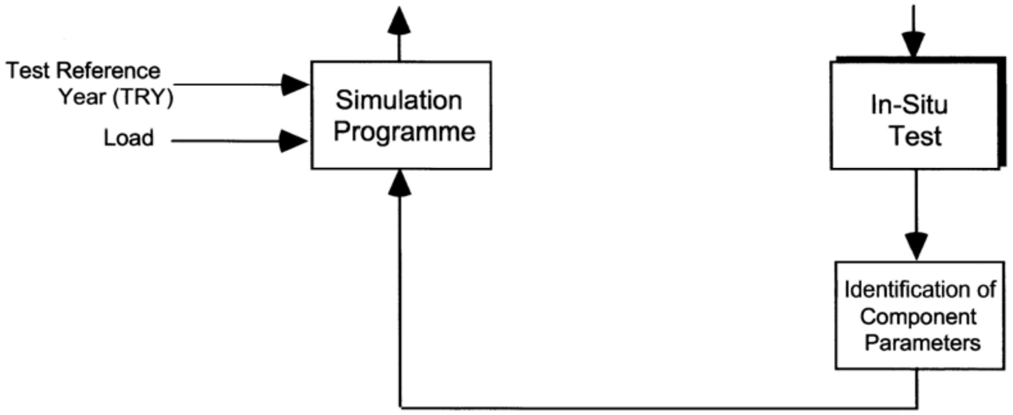

Test Reference Year (TRY)
Load
Simulation Programme
In-Situ Test
Identification of Component Parameters

Figure C.2 — Principle of the short-term test and of the subsequent long-term system performance prediction

Measurement of data as requested in C.4.3.2 should take place continuously over a certain time interval until the criteria for termination of the measurement, indicated in C.4.4, are met. The measurement should be carried out under "operation conditions" of the system, according to C.3.1.

After the criteria for termination of the test have been met, the collector array parameters should be identified. The identified parameters are thereafter used for the prediction of the long-term performance of the system. Local input data are hourly values of meteorological data, which are available, e.g., from test reference year (TRY), and the load data specific for the system being tested.

C.4.3 Measurements

C.4.3.1 Conditioning

See C.3.2.1.

C.4.3.2 Procedure

During the monitoring period the measurement data indicated in Table C.2 should be continuously recorded.

Table C.2 — Variables to be measured during system test, and corresponding maximum sampling intervals

Symbol	Unit	Variable	Maximum sampling interval s
ϑ_{cw}	°C	mains water temperature	5
ϑ_{S}	°C	store draw-off temperature	5
ϑ_{rci}	°C	fluid temperature at circulation loop inlet	5
ϑ_{rce}	°C	fluid temperature at circulation loop outlet	5
ϑ_{ci}	°C	collector fluid inlet temperature	5
ϑ_{CO}	°C	collector fluid outlet temperature	5
$\dot{V}_{C}$	m^3/s	volume flow rate in collector loop	5
$\dot{v}_{re}$	m^3/s	volume flow rate in circulation loop	5
$\dot{V}_{S}$	m^3/s	volume draw-off flow rate from store	5
G_h	W/m^2	hemispherical irradiance on tilted plane	5
G_g	W/m^2	global irradiance, i.e. horizontal (optional)	5
G_d	W/m^2	diffuse irradiance on tilted plane	5
$\vartheta_{c,amb}$	°C	collector ambient air temperature	30
$\vartheta_{S,amb}$	°C	store ambient air temperature	30
v	m s^{-1}	surrounding air speed	10
P_{aux}	W	auxiliary power	1

NOTE Integrating instruments should be applied for auxiliary power and flow rates.

The values needed for determination of the system power, such as temperature difference, volume draw-off flow rate and auxiliary power should be obtained with a period not exceeding 1 s. The data for other variables should be obtained with periods of at least 30 s for further processing.

The sampled values should be continuously integrated and averaged.

The integrated values for each variable should be computed over a recording interval and stored.

Maximum recording interval is 1 min. The data recording interval may vary during the measurement sequence.

The monitoring of the collector array and collecting of data should be continued until the criteria for termination of the test as described in C.4.4 are met.

C.4.4 Criteria for termination of the test

In order to be able to check the store energy balance and the collector array energy gain, it is necessary to collect data continuously over a certain time period with reasonably good weather conditions.

So, the first criterion for termination of the test applies to weather requirements during the test. The weather conditions which should prevail during the test are:

- The irradiation integrated over the test should be higher than 200 MJ/m^2.
- The total time with irradiance exceeding 500 W.m^2 should exceed 50 % of the total test period.

The second criterion applies to the collector operation conditions necessary for accurate identification of the collector parameters.

These general operation conditions are fully represented by four driving variables:

a) the difference between the mean collector fluid temperature ϑ_m and the collector ambient air temperature $\vartheta_{c, amb}$,

b) the reduced temperature $T^* = (\vartheta_m - \vartheta_{c,amb})/G_h$,

c) the surrounding air speed, and

d) the angle of incidence of the direct solar radiation on the collector plane.

The wind speed range depends on the climate where the system under test is located. The range scanned during the test should be representative for that climate.

The requested ranges of variation for other driving variables are listed in Table C.3.

Table C.3 — Range of variations of the driving variables to be scanned during a test outdoors

Driving variable	Requested range of variation
($\vartheta_m - \vartheta_{c,amb}$ (while $G_h > 500$ W/m^2)	10 K to 45 K or 65 K [1)]
reduced temperature T^* (G_h>500W/m^2)	0.02 m^{2}K/W to 0.12 m^{2}K/W or 0.2 m^{2}K/W[1)]
angle of incidence of direct solar radiation	10° to 70°
[1)] Whenever possible, the requested range of variation should be extended up to that value.	

C.4.5 Identification of collector array parameters

The theoretical model of the collector ("dynamical collector test model") should be used as defined in KS 1851-2.

The identification of the parameters of the theoretical model should be carried out by an appropriate mathematical tool for identification of parameters as defined in KS 1851-2 ("dynamical collector test model").

The collector array parameters determined by the parameter identification program should be listed together with the associate standard deviations.

C.4.6 Criteria for the acceptance of the test results

The main aim of the test is to enable a prediction of the long-term system performance under actual weather and load conditions.

An incorrect prediction of long-term system performance are mostly caused by:

a) incorrect computation of irradiance on the tilted plane,

b) the collector array does not deliver the energy expected by the designer and

c) the in-situ storage performance does not correspond to the designed one.

In order to eliminate these possible sources of error the basic criteria for acceptance of the test results, given in C.4.6.1 to C.4.6.3, should be fulfilled.

If one of these criteria is not met, the corresponding simulation model should be checked. If the simulation model is correct, and no error is detected in the operation of the system, the test should be prolonged for 2 additional days (daily irradiation exceeding 12MJ/($m^2 \cdot$d)). This procedure should be repeated until the criteria are met.

C.4.6.1 Irradiance on the tilted plane

Only the days where the irradiance exceeds 12 MJ/($m^2 \cdot$d) should be considered.

C.4.6.2 Collector array

The energy delivered by the collector (on the daily basis) should not differ by more than 10 % from the energy predicted by the collector array design parameters over the operational conditions during the test period.

In addition, the identified collector parameters should be accurately determined. The identified parameters are acceptable if the standard deviations do not exceed the following values:

a) 1 5 % for the overall heat loss coefficient of collector array U_L,

b) 20 % for the incidence angle modifier $K\tau\alpha$

c) 10 % for the collector array heat capacity C_c and

d) 3 % for the zero-loss efficiency of collector array η_0.

If the standard deviations of any of the identified parameters listed in Table C.4 exceed their permissible values the identification procedure should be repeated using reasonable assessed values for these parameters in equation (22) of KS 1851-2. Hence the remaining parameters only should be calculated by the identification procedure.

Table C.4 — Permissible standard deviation for secondary collector parameters

Parameter	Symbol[*)]	Permissible standard deviation
Temperature dependance of the overall heat loss coefficient	C_2	15%
Wind speed dependance of the overall heat loss coefficient	C_3	15%
Sky temperature dependance of the overall heat loss coefficient	C_4	15%
Wind speed dependance of the zero-loss collector efficiency	C_6	15%
*) According to equation (22) in 6.3.4.8.2 of KS 1851-2		

C.4.6.3 Store

Energy drawn-off from store (on a daily basis) should not differ by more than 10 % from the energy predicted using the store design parameters over the particular operational conditions during the test period. Here, the energy delivered by the collector array is used as a measured input variable.

C.4.6.4 Final check

After the criteria in C.4.6.1 to C.4.6.3 are met, the complete solar heating system model should be validated comparing the measured with the predicted useful energy gain and using the following data:

a) component data,

b) weather data (the irradiance on the horizontal plane should be used), and

c) the load conditions as occurred during the validation test.

The energy predicted by simulation should not differ by more than 10 % from the measured energy output on a daily basis.

C.4.7 Test report

The test report should include:

- Detailed description of the system under test.
- Detailed description of the test installation and instrumentation specifications (manufacturer, accuracy).
- Graphical presentation of the measured energy gain of the collector array, as well as that predicted using the collector design parameters.
- Graphical presentation of the measured energy delivered to the user from the storage vessel(s) as well as that predicted using the storage design parameters.
- The identified parameters of the collector array with associate standard errors and their correlation matrix, if available. A Comparison with the design collector array parameters should be stated as well.

— A diskette with data files and the file(s) resulting from the statistical data evaluation.

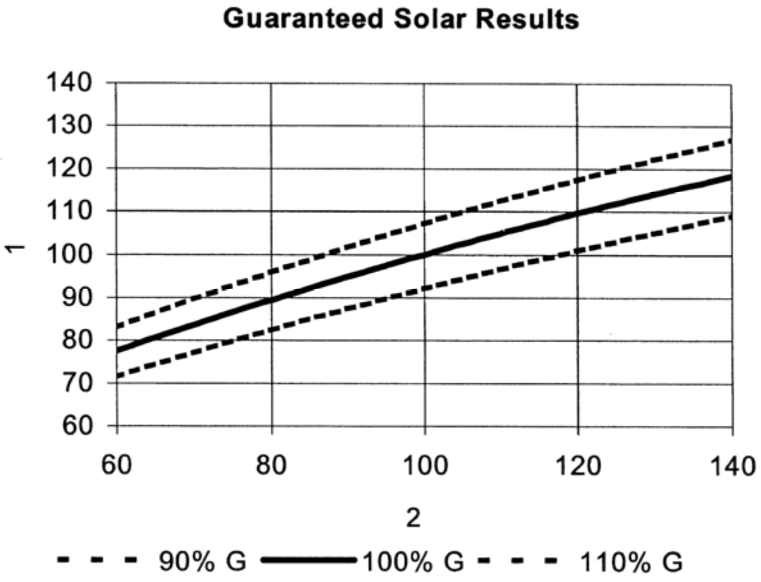
NOTE Clause 8 gives additional information on the contents of the test report.

C.4.8 Prediction of the yearly system gain

On the basis of the component data (either by in-situ measurement or manufacturer data) the detailed simulation should be performed by the same computer program as in 4.6, using actual load volume and profile and the test reference year for a particular site.

Additionally, simulation runs should be performed with the load level varying from 70 % to 120 % of the actual one and the yearly irradiation from 90 % to 110 % of that of the test reference year.

NOTE Figure C.3 gives an example of the predicted performance dependence on load level and irradiation.



Key
1 Out in %
2 Load scale factor in %

Figure C.3 — Example of the predicted performance dependence on load level and irradiation for a solar domestic hot water heating system (see [8]).

Annex D
(informative)

Long-term monitoring

D.1 General

Long-term monitoring gives the company operating the solar heating system after commissioning (referred to below as the "client") a simple supervision tool

a) to determine the solar contribution to the total heat load, and

b) to get an indication on malfunctions or degradations of the solar heating system.

The final long-term goal is to get the maximum benefit from the initial solar investment as well as to minimize the consumption of auxiliary energy and the resulting environmental impact.

Long-term monitoring of a solar heating system is very similar to that of a common heating plant. In this annex, solar energy specific aspects are emphasized.

In order to reduce the cost of long-term monitoring as much as possible, the physical key quantities monitored should be integrated continuously, and the figures displayed by the integrators be recorded at regular time intervals (mostly in coincidence with the supervision time intervals).

The data which should be monitored include:

a) the hemispherical solar irradiation in the plane of the collector array(s)

b) the total load of that part of the system to which solar energy is supplied, and

c) the solar contribution of the solar heating system.

The interface where the heat transferred from the solar part to the conventional part of the system (i.e. the solar contribution) is measured, should be specified individually for each system, depending on the hydraulic scheme and the control concept.

NOTE 1 It is always possible to include more physical quantities into the measuring programme, giving a higher priority to some of them according to additional supervision objectives. In that case, the additions (in comparison to this annex) should be fully documented.

Long-term monitoring starts when the expected system performance has been confirmed by the short-term system testing according to annex C.

The monitoring procedure is described for a large custom-built system with short-term storage (Class A or B according to 5.2 of KS 1855-1).

NOTE 2 Future updates of this Kenya Standard may consider other system types, e.g. such with seasonal storage, when more experience on those types is available.

D.2 Evaluation chart

The evaluation chart is a diagram showing the solar contribution of the solar heating system as a function of the solar irradiation in the collector plane for different load levels. It should be used as a reference to evaluate the system performance (see D.4). The evaluation chart should be established at design time and delivered to the client with the system technical documentation. It is obtained similarly to the system energy balance and should be based on the same weather data and load assumptions (see 6.7.3.1 in KS 1855-1).

The evaluation chart should display different trends of solar contribution variation as a function of the load level and other possible parameters having a strong influence on the system performance.

NOTE The range of load level variation should be 70 % to 120 % of the nominal value used for dimensioning.

Weekly data are preferred in evaluation charts, as they match up to the most common time interval in use in heating plant supervision. However, daily and monthly data may also be plotted in those charts.

If monthly performance data have been obtained at design time, they may be converted to weekly average values for the corresponding months, in order to display only weekly data in the evaluation chart. Similarly, daily values may be grouped to weekly data in the evaluation chart. Finally, values from short-term testing according to annex C, related to any time intervals, may be converted to weekly (average) values and included in the evaluation chart.

D.3 Monitoring equipment

The monitoring equipment described here is kept at the lowest possible level of instrumentation in order to minimize cost; accordingly, simple methods of evaluation have been chosen (see D.4).

More sophisticated equipment with a higher time resolution, additional physical quantities to be monitored and/or automatic data acquisition and display, is always possible. Accordingly, the evaluation chart should be supplemented at design time. At least all data considered in the evaluation chart should be monitored, and most data monitored should be considered in the evaluation chart.

The simplest monitoring equipment includes:

a) a heat meter to measure the heat load of the system. If solar energy is supplied to a part of the system only, e.g. for hot water preparation, the load of this part should be monitored.

b) heat meter to measure the solar contribution related to the above mentioned heat load.

c) an integrator of the solar irradiance in the collector plane. If different collector orientations exist within the system, the solar irradiance can be measured in the different planes and considered in evaluation charts, according to the client's wishes.

Instrumentation used in the long-term monitoring should be an integral part of the system, a part included from the very beginning of the design process. If adequately foreseen, it may also be used for adjustments at the initial operation time.

D.4 Data analysis

The monitored data should be plotted in the evaluation chart for direct visual comparison with the expected values. For their interpretation the different load levels as well as other parameters included in the evaluation charts (see D.2) should be considered.

The system is working properly if the monitored data fit to the values given by the evaluation chart, within the accuracy limits agreed to by the client. If a larger discrepancy is observed, there is evidence for malfunction or degradation of the solar heating system.

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